LA-UR- 97-728

Approved for public release; distribution is unlimited.

CONF-970335--46

Title: A COMMON-SENSE PROBABILISTIC APPROACH TO ASSESSING INADVERTENT HUMAN INTRUSION INTO LOW-LEVEL RADIOACTIVE WASTE AT THE NEVADA TEST SITE

Author(s): Paul Black, Neptune and Co. Inc., NM
Beth Moore, U.S. Dept. of Energy, NV
Bruce Crowe, LANL, Las Vegas, NV
Mark Hooten, Neptune and Co. Inc., NM
Kelley Black, Neptune and Co. Inc., NM
Stuart RawlinsonBechtel Nevada Corp. NV
Lawrence Barker, Bechtel Nevada Corp NV

Submitted to: WM Symposia, Inc., and ER '97, Tucson, AZ

Los Alamos
NATIONAL LABORATORY

DISCLAIMER

A COMMON-SENSE PROBABILISTIC APPROACH TO ASSESSING INADVERTENT HUMAN INTRUSION INTO LOW-LEVEL RADIOACTIVE WASTE AT THE NEVADA TEST SITE

by

Paul Black[1], Beth Moore[2*], Bruce Crowe[3], Mark Hooten[1], Kelly Black[1], Stuart Rawlinson[4], and Lawrence Barker[4]

1 - Neptune and Company, Inc., Los Alamos, New Mexico
2 - U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada; * Presenter
3 - Los Alamos National Laboratory, Las Vegas, Nevada
4 - Bechtel Nevada Corporation, Las Vegas, Nevada

ABSTRACT

The United States Department of Energy (DOE) Order 5820.2A requires each site disposing of low-level radioactive waste to prepare and maintain a site-specific performance assessment (1) to determine potential risks posed by waste management systems to the public, and the environment, and (2) to compare these risks to established performance objectives. An *inadvertent human intruder* is a person who, without knowledge or intent, disturbs the waste after the period of institutional control ceases (assumed to be 100 years) and is exposed to radioactivity. The DOE Nevada Operations Office, Waste Management Program recently completed a one-year study of site-specific scenarios for inadvertent human intrusion by drilling into buried low-level radioactive waste sites, as part of ongoing performance assessment studies. A process involving participation of stakeholders, public, and scientists was used to develop likely homestead and community scenarios for inadvertent human intrusion at the Nevada Test Site (NTS) Area 3 and Area 5 Radioactive Waste Management Sites. Intrusion scenarios focus on possible penetration of buried waste through drilling for sources of groundwater. Past performance assessments of low-level radioactive waste sites at the NTS were deterministically based, assuming that inadvertent human intrusion will occur at a probability of 100 percent during the 10,000-year evaluation period. This expert elicitation was conducted as a first step towards bringing a probabilistic perspective to this aspect of a performance assessment. The Nevada Test Site approach to site-specific inadvertent human intrusion determination is not dependent on the waste form, and may be applicable to other DOE or commercial facilities.

A Subject Matter Expert panel, comprised of ten disciplines ranging from the social sciences to engineering and drilling, was convened to assess the site-specific probability of inadvertent human intrusion through a formal process of expert elicitation. The probability of drilling penetration into waste was judged to be driven primarily by two settlement scenarios: (1) scattered individual homesteaders, and (2) a community scenario consisting of a cluster of settlers that share drilling and distribution systems for groundwater.

Management control factors that may affect inadvertent human intrusion were developed in the stakeholder workshop and defined during the Subject Matter Expert elicitation sessions. Management control factors include institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers. The Subject Matter Experts concluded that institutional control and site knowledge may be important factors for the first few centuries, but are not significant over the evaluation period of 10,000 years. Surface barriers can be designed that would deter the siting of a drill rig over the waste site to an effectiveness of 95 percent. Subsurface barriers and placards and markers will not as effectively prevent inadvertent human intrusion.

The important factors affecting probabilistic assessment of the settlement and community scenarios are the remoteness of the alluvial valleys of the Nevada Test Site, and the presence of playas and surface-subsidence craters, which are unlikely to be settlement sites. The highest probability of intrusion was driven by a secondary community scenario. This scenario was described as a community settlement that develops from location of an industrial-technological complex in Jackass Flats (located in the southwest portion of the Nevada Test Site). Homestead and community scenarios were considered by the panel to render a site-specific probability of around 10 percent for inadvertent human intrusion. If management controls are designed and implemented effectively, then the probability of inadvertent human intrusion can be reduced to less than one percent.

INTRODUCTION

The U.S. Department of Energy, Nevada Operations Office (DOE/NV) operates, oversees, and has responsibility for future closure of Radioactive Waste Management Sites (RWMSs) located in Frenchman Flat and Yucca Flat at the Nevada Test Site (NTS; Figure 1). The DOE/NV Waste Management Program provides low-level radioactive disposal capability for NTS-generated waste and other DOE-approved waste generators. Radioactive waste disposal operations began at the NTS in 1961. Low-level radioactive, transuranic, mixed, hazardous, and classified wastes have been disposed in pits, trenches, landfills, and greater confinement disposal boreholes.

A requirement for operation of low-level radioactive waste disposal sites under DOE Order 5820.2A is the preparation and maintenance of a site-specific performance assessment (PA). A PA is a series of analyses conducted (1) to determine potential risks posed by waste management systems to the public and the environment, and (2) to compare these risks to established performance objectives (dose thresholds). Results of the PA are used to effect regulatory decisions regarding disposal site design, operation, safety, waste acceptance criteria, and site characterization. A PA has been conducted, and tentatively approved, for the post-1988 disposal units within the Area 5 RWMS, located in northern Frenchman Flat (Figures 1 and 2; Shott et al., 1996). A second PA is in preparation for the Area 3 RWMS, located in southern Yucca Flat (Figures 1 and 2).

Each PA must evaluate facility operation based on four performance objectives, briefly summarized as follows:

1. Protect public health and safety in accordance with applicable environmental standards and DOE Orders.
2. Assure that an effective dose equivalent to any member of the public does not exceed 25 millirem per year (mrem/yr).
3. Assure that an effective dose equivalent received by an individual who inadvertently intrudes into the waste after loss of institutional control (assumed to be 100 years) will not exceed 100 mrem/yr for continuous exposure and 500 mrem/yr for a single acute dose.
4. Protect groundwater resources consistent with Federal, state and local regulations and requirements.

The third performance objective evaluates the likelihood that disposed radioactive waste may adversely impact an inadvertent human intruder at some time during the next 10,000 years (the evaluation period). An inadvertent human intruder is a person who, without knowledge or intent, disturbs or uncovers disposed radioactive waste and receives radiological exposure, either directly or through secondary pathways.

This paper describes a site-specific approach for determining the probability of inadvertent human intrusion (IHI) for the intruder-drilling scenario at the Area 3 and 5 RWMSs through a process known as expert elicitation. Specifically, probabilities of drilling inadvertently into disposed waste were assessed by formally eliciting expert judgments from a panel of Subject Matter Experts (SMEs), relying on their combined training and experience. This project was conducted for two primary reasons:

1. DOE Order 5820.2A and guidance provided by the DOE Performance Assessment Task Team (Wood et al., 1994) and Case and Otis (1988) recommend the development and use of site-specific, credible scenarios for dose exposure calculations based on an understanding of current conditions.
2. The evaluation of problematic waste streams under the PA (Brown et al., 1996), such as those characterized by high-specific activity, often requires a more thorough and rigorous approach, better handled by probabilistic methods than by standard deterministic analyses.

The organization of this paper is intended to provide the reader with pertinent background and scope to understand the base assumptions of the elicitation, the development of influence diagrams, the elicitation process and results, and conclusions of the study.

BACKGROUND AND SCOPE

The Area 5 RWMS PA followed established practice by using intruder scenarios similar to those used in previous PA studies for disposal of low-level radioactive waste (Shott et al., 1996). Three types of scenarios were considered:

1. The intruder-construction scenario assumes a homesteader builds a house over a waste disposal site and excavates a foundation into the buried waste.

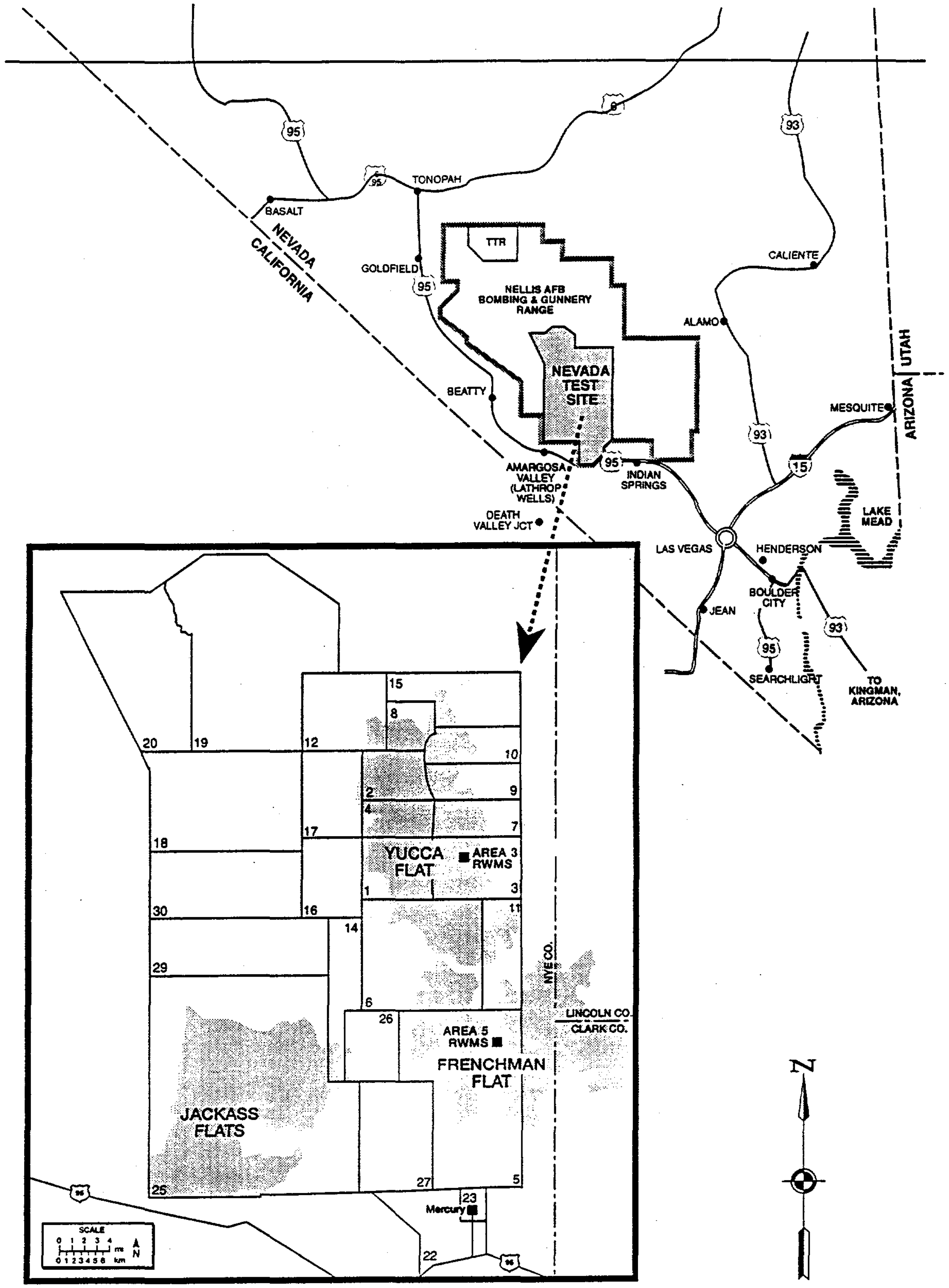

Figure 1. Location of the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs) within the Nevada Test Site and southern Nevada.

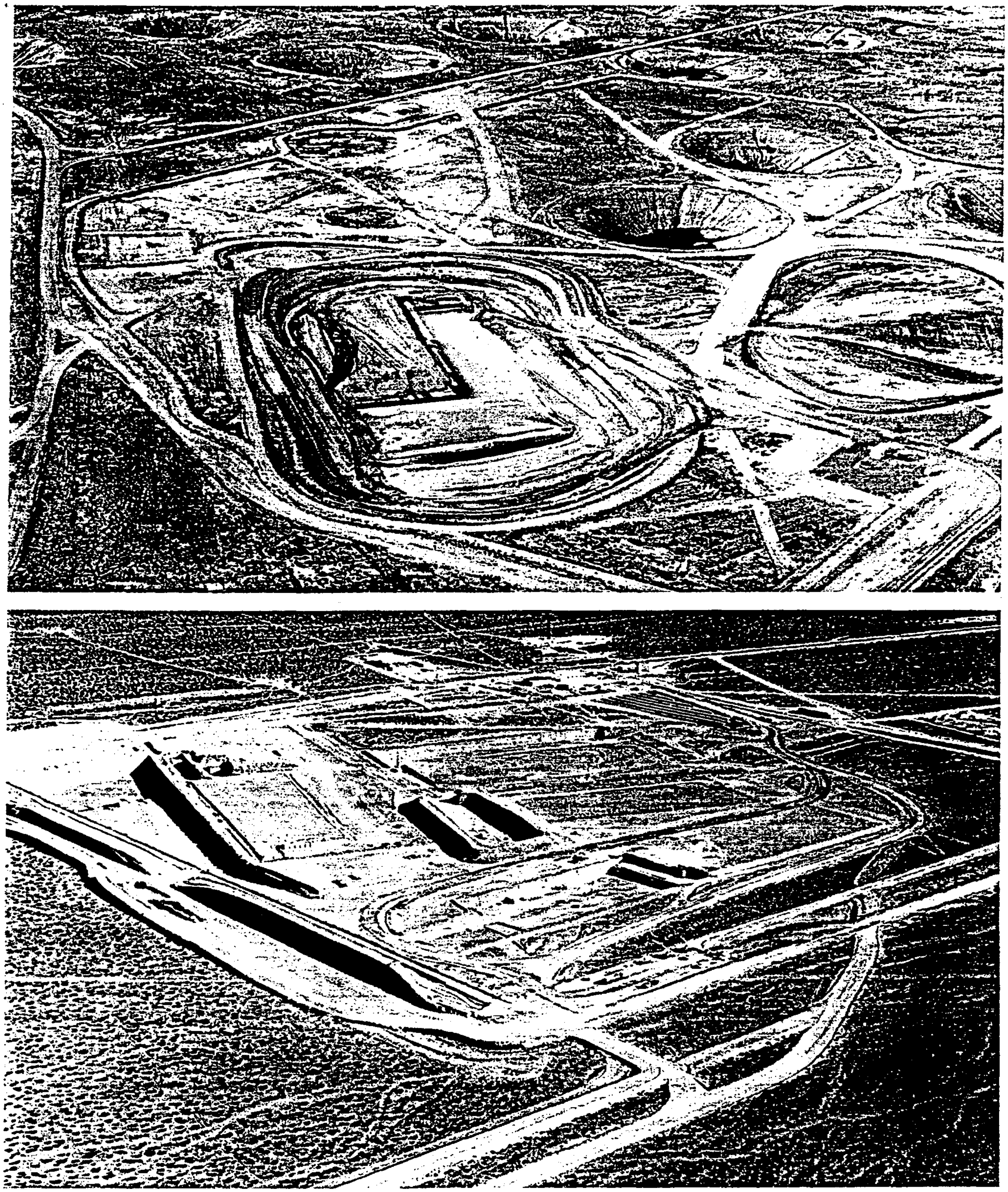

Figure 2: Oblique aerial photographs of the Area 3 Radioactive Waste Management Site (above), and the Area 5 Radioactive Waste Management Site (below) at the Nevada Test Site.

2. The intruder-discovery scenario is identical to the intruder-construction scenario, but assumes the intruder recognizes the hazardous nature of the excavated waste.
3. The intruder-drilling scenario assumes a future settler drills for groundwater through a waste disposal site, and is exposed through various pathways to contaminated drill-cuttings.

The elicitation focuses on the intruder-drilling scenario, because the results were applied to a PA evaluating deep disposal options for a problematic waste stream (high-specific activity, low-level radioactive waste). For deep disposal configurations, the intruder-drilling mechanism is usually the limiting scenario for PA performance objectives. A preliminary PA often starts with screening calculations to evaluate the limiting scenario against the appropriate performance objectives. The probabilities derived in this study are limited to use in dose calculations for the intruder-drilling scenario. However, the scenarios developed by the SMEs and input obtained about the management controls options are directly applicable to PAs that evaluate shallow-land waste disposal, with necessary modifications.

The exposure scenario of interest in this study is the intruder-driller. This scenario considers an individual, the "homesteader," who unknowingly breaches containment of the waste by drilling to groundwater. The drilling process transports waste to the surface where the drill cuttings are mixed with soil in the homesteader's vegetable garden. Case and Otis (1988) indicate that the selection of post-institutional control scenarios can be a fairly subjective process, therefore justifying the use of the elicitation process for scenario development. Furthermore, Case and Otis indicate that "scenario construction should consider current patterns of activity in the area," in which case it is appropriate to consider scenarios that go beyond the default scenarios presented in Wood et al. (1994). While the default "homestead" scenario served as the starting point for this study, other scenarios are suggested and developed that account for potential "community" scenarios.

A traditional PA assumes that IHI *will* occur (a probability of one) during the course of the 10,000-year time frame to which the PA is applied. This deterministic approach may be reasonable for waste disposal sites near populated areas where the likelihood of human intrusion is increased. However, IHI is much less likely in the remote Mojave desert setting of the NTS. The RWMSs are situated in alluvial basins where the average annual rainfall is less than 10 centimeters, near-surface processes are dominated by evapotranspiration, permanent surface-water features are rare, and depths to groundwater exceed 250 meters (Figure 2; Shott et al., 1996; Winograd, 1981).

The Waste Management Program decided to evaluate IHI in a probabilistic manner at the NTS to generate more realistic PA results. Instead of assuming that human intrusion *will* occur, a probabilistic study was designed to estimate the likelihood that IHI will occur, taking into account site-specific factors and scenarios related to the RWMSs. Case and Otis (1988) present an interpretation of DOE Order 5820.2A that provides verification that a probabilistic approach that accounts for site-specific circumstances is consistent with regulatory guidelines. The probabilistic study described in this paper was conducted in calendar year 1996. The study is reported in Black et al. (1996).

ELICITATION

Overview

Assessment of the probability of IHI was completed through an expert elicitation. Although this approach is justifiable technically, it is important that the process includes development of models and assumptions, and sharing of information among all participants to ensure that the results are credible. This process involves a number of components that are used to build a solid foundation prior to the SME elicitation sessions. Initial steps taken in the process focused on obtaining sufficient information to identify the areas of expertise needed to perform the assessment. Preliminary models were developed in the form of "influence diagrams." Influence diagrams show important factors or variables, and the relationships between those variables, at a simplified level that facilitates natural interpretation (Figure 3).

The elicitation was conducted using a three-step process:

1. Developing the logic of the pertinent variables affecting IHI through development of influence diagrams for the scenarios and the management controls
2. Holding open workshops involving participation of stakeholders, scientists, and the public to examine the logic and acceptability of the approach taken for the probabilistic study
3. Assessing the probabilities of intrusion into waste units by convening and formally eliciting expert judgments from a panel of SMEs

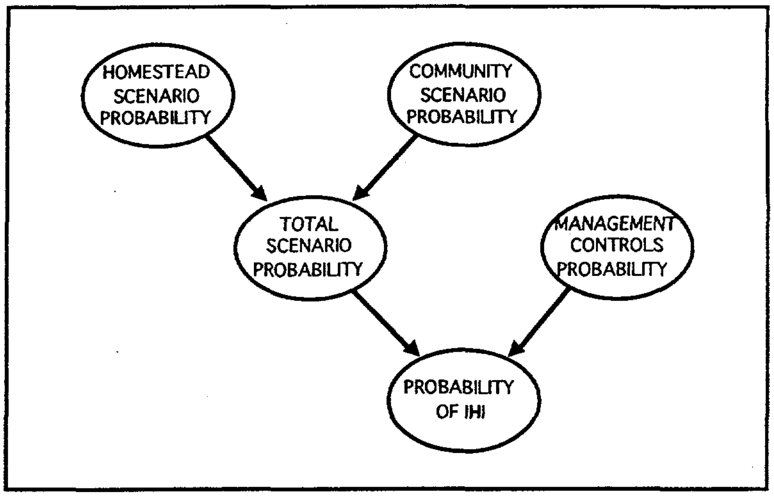

Figure 3. Influence diagram depicting the major components of the probability of inadvertent human intrusion assessment.

Expert judgment has proven to be a particularly useful tool for evaluating probabilistic estimates for rare, or poorly understood, phenomena and for forecasting future events (Kotra et al., 1996; Morgan and Henrion, 1995; Meyer and Booker, 1991; Keeney and Raiffa, 1993; Raiffa, 1968). These topics have significant uncertainty that commonly cannot be reduced by conventional means of data gathering. The issue of IHI for the RWMSs in Frenchman and Yucca Flats involves multiple factors with largely non-reducible uncertainty. There is uncertainty in the future missions and institutional control of the NTS, uncertainty in the viability, values and practices of future societies, and uncertainty in future hydrogeologic processes that make arid desert lands either more or less desirable to society.

The foundation of the approach taken in this study is summarized as follows:

- Specify assumptions and models
- Gain acceptance from relevant stakeholders that the assumptions and models are reasonable
- Obtain relevant input to fulfill the needs of the models
- Calculate the probability of IHI as a consequence of the assumptions and the model input

Base Assumptions

The initial steps in this probabilistic study involve developing a model of how IHI occurs. This analysis could become hopelessly complex if every mechanism of possible IHI were considered, given the uncertainty of future changes in society. Therefore, some basic conditions were established for the modeling process.

The current boundaries of the NTS are subject to institutional control. Open public access to waste disposal sites is prohibited. Future IHI can only occur if institutional control of the NTS ceases, and knowledge of the existence and location of waste disposal sites is not in the public domain. As long as institutional control of the NTS is actively maintained, it is reasonable to assume that all public development on the site will be precluded and that IHI will be avoided. Even after institutional control is lost, knowledge of the hazardous nature of the site may be maintained for some period of time and should continue to deter public incursion. Site knowledge could be enhanced by the presence of some form of permanent surface marker or warning sign. Two additional factors could deter drilling for groundwater, should institutional control and site knowledge become ineffective. Surface barriers can be built to restrict or prohibit access to the land immediately above a waste disposal site, and subsurface barriers can be constructed to prevent completion of a drilling operation. This set of conditions underlie the model and are collectively termed "Management Controls."

An overview of the modeling process, including the scenario components and the management controls factors, is shown in Figure 3. The scenarios and the management controls factors are subject to evaluation through the elicitation process. The homestead and community scenarios are evaluated separately, and then are combined to provide a total scenario probability of IHI. This represents the probability of IHI, assuming all management controls factors are ineffective. If any of the management controls are effective, it is assumed that IHI cannot occur. The next step involves evaluation of the potential effectiveness of the management controls. The results for management controls are then combined with the conditional scenario results to provide an overall assessment of the probability of IHI. The management controls module acts as a probability modifier for the scenario probabilities.

A second assumption addresses prediction of future changes in society and technology. Past studies have shown that many aspects of science and technology, particularly social sciences that are more susceptible to human influence, are inherently unpredictable (Casti, 1990). At best, stochastic or probabilistic models of future events can be developed. Accurate prediction of most events is impossible (for example, population growth, technology development, societal patterns, climate change, etc.). Consequently, a working assumption for this probabilistic study of IHI is that forecasting of future patterns must be based on current technology and current societal practices. This presents a potential credibility problem for future PAs. To counteract this potential problem, a decision was made to periodically revisit the probabilistic estimates, if changes occur in society or technology that could significantly affect the results of the evaluation. Periodic review of intrusion at an interval of 25 years was proposed as an alternative to dealing with the largely unbounded uncertainties of predicting the future.

The final assumption for the basic approach concerns the mechanisms by which an inadvertent intruder who gains access to NTS chooses to settle in a remote alluvial valley. A number of scenarios are possible, including both homestead and community scenarios, and a range of factors may affect the outcome of the probabilistic assessment of IHI for these scenarios. Examples of such factors include the suitability of the land surface for expected settlement activities and the hydrogeologic setting of the site, that is, future groundwater resource availability. The factors and the models developed by the SMEs for each scenario provided the necessary focus for the expert elicitation.

Elicitation Process

Preliminary influence diagrams include factors such as the number of homesteads, community lifetime, well density, well lifetime, depth to groundwater, and topographical features. An external review was conducted through a workshop including stakeholders, scientists, and public representatives. The workshop was a key element of the process that ensured that stakeholders understood and shared a basic agreement in the credibility of the probabilistic approach (Black et al., 1996). Useful outcomes of the stakeholder and public interactions were to focus on making the probabilistic assessments specific to Nevada, and to validate the logic used in the influence diagrams for the management controls module and the homestead and community scenarios. In particular, the workshop participants suggested that current population trends indicate that an urban scenario is plausible and should be considered for evaluation. Hence, the rationale for development of site-specific, credible community scenarios. The workshop participants fully endorsed "periodic review of intrusion," with an acknowledgment that such an approach will realize success only with assurances that sufficient funds are made available. A scientific review was also performed by convening a group consisting of leading scientists from government institutions and private companies. The peer review group provided critical input on details of the approach, and confirmed the general findings from the workshop.

The influence diagrams include factors that directly affect the potential for IHI to occur. The first step in selecting SMEs was to identify relevant disciplines to address these factors. Ten disciplines were chosen: agronomy, anthropology, demography, economic geology, geotechnical engineering, hydrogeology, hydrology, land-use planning, sociology, and drilling technology. Selection criteria for the disciplines included demonstration of classic training in the discipline, familiarity with the discipline application in the arid Southwest, and some familiarity with probability and statistics.

The selected SMEs were provided critical references and background materials prior to convening the first elicitation session to ensure a sufficient knowledge base for an effective session. The first elicitation session began with a field trip that familiarized the SMEs with the Area 3 and Area 5 RWMSs, Waste Management Program functions, topological features, hydrologic and geologic processes, and communities within the vicinity of NTS. The remainder of the first session was dedicated to structuring the influence diagrams. The SMEs were presented preliminary influence diagrams and were encouraged to debate the merits and deficiencies of the diagrams, then to modify them to reflect their consensus opinions. The SMEs' input resulted in the final structuring of the influence diagrams. The first session ended with general training on probabilistic concepts used in expert elicitations. The SMEs became familiar with methods for eliciting probability distributions and with potential sources of bias that can arise in the elicitation process.

The second session focused on formal elicitation of the probabilistic input required to fulfill the specifications of the influence diagrams. The elicitation involved assessment of quantile values from the SMEs using standard methods of expert judgment (Black et al., 1994; Keeney and Raiffa, 1993; Meyer and Booker, 1991; Raiffa, 1968). To ensure that inputs from the SMEs were recorded accurately, and for quality assurance purposes, the elicitation sessions were taped and several sets of written notes were archived. The SMEs were also provided a summary report that described their input. Each SME verified that their input was recorded accurately and was used appropriately. They were also asked to provide an evaluation of the elicitation process. This provided useful feedback on the practical adequacy of the elicitation approach, as well as the validity of and inputs to the model.

The remainder of the process involved the mathematical methods used to propagate the elicited input through the influence diagrams, and the presentation of the assessment of the probability of IHI. Probability distributions were fit to the elicited inputs, and Monte Carlo simulation techniques were used to propagate the input distributions through the influence diagrams. The simulations produce an assessment of the probability of IHI for each scenario when management controls are considered ineffective. These results are then adjusted for the potential effectiveness of management controls to provide a final assessment of the probability of IHI.

Inadvertent Human Intruder Scenarios

Results of the elicitation for the homestead and community scenarios are discussed in this section. Elicitation was performed by forming sub-groups of SMEs with expertise pertinent to specific factors. Other members of the SME panel were given the opportunity to comment, ask questions, or disagree with the sub-group experts. A variety of elicitation methods were used that are described in Black et al. (1996).

A consensus step at the start of the elicitation was definition of the base assumptions by the SME panel. The SMEs agreed with the workshop findings--that using current knowledge of society is the only credible approach to a probabilistic assessment of IHI. Further, the SMEs agreed that a periodic review of intrusion every 25 years is necessary as the current knowledge base changes. Specifically, if societal or technological changes significantly affect the results. The SMEs also indicated that sufficient funds need to be established to ensure that periodic review will occur.

The SMEs were provided complete freedom to discuss and revise the scenarios as necessary. This process resulted in acceptance of the homestead scenario and refinement of the community scenario. Three separate community scenarios were identified:

1. A small community located in the alluvial basins of Frenchman or Yucca Flats (Base Community Scenario)
2. Urban expansion of Las Vegas north up the valley corridor and into the alluvial basins of NTS, including "commuting homesteaders" (Las Vegas Expansion Scenario)
3. A small community located in Jackass Flats, or in another area nearby Frenchman and Yucca Flats, including "commuting homesteaders" (Jackass Flats Scenario)

The SMEs defined "commuting homesteaders" as settlers who commute regularly from their homes located outside of the community or urban resource base. This was distinguished from the homestead scenario for which homesteaders were assumed to be isolated from any central community. The homestead scenario, combined with the three community scenarios, yield the four scenarios that the SMEs considered in this study.

The four scenarios follow a common basic model (Figure 4). The probability of IHI was evaluated separately for each scenario. Inputs obtained from the SMEs for each scenario provided information relevant to the top-level factors: the number of wells at a point in time (well density) and the well lifetime. Elicitation of these inputs depended on other factors specific to each scenario. The inputs were used to assess the total number of wells that are anticipated to be drilled in Frenchman and Yucca Flats during the evaluation period.

Area estimates of Frenchman and Yucca Flats were estimated with GIS and mapping techniques, and the area of the waste footprint is assumed to be two acres. The total number of wells and the ratio of area of the waste footprint to the area of the alluvial basins were required to a determine the probability that at least one well would intersect the waste footprint, causing an intrusion event.

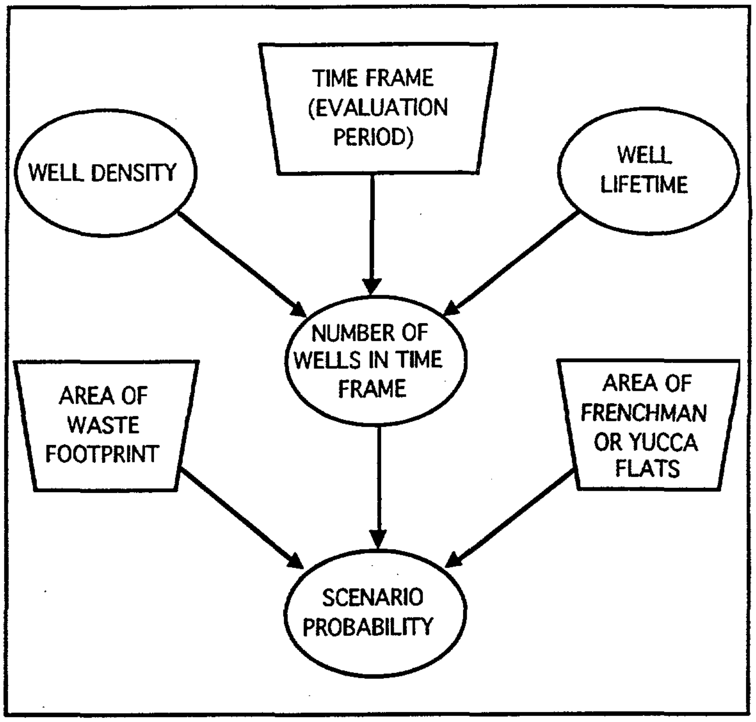

Figure 4. Influence diagram of factors in the basic scenario model.

A number of factors were included in the scenario-specific influence diagrams, all of which effect assessment of the number of wells that will be drilled during the evaluation period. For example, suitability of the land surface and hydrogeologic factors may influence the likelihood of establishing a settlement in the vicinity of the RWMSs. The suitability of the land surface may be influenced by the remoteness of the alluvial basins, playas (dry lakes) that are contained within these basins, and surface-collapse craters that were formed by underground testing (Figure 2). The SMEs attempted to establish a balance in the selection of factors included in the influence diagrams. This required a conscious effort to ensure that the number of variables were sufficient to document and defend the probabilistic analyses, yet were not so numerous that the elicitation process became onerous, and could not be completed in a reasonable time frame.

Homestead Scenario: The homestead scenario was further defined by the SMEs in terms of isolated and independent homesteads. Assumptions for the homestead scenario include:

1. The homesteads are isolated.
2. Each site will have one active water well within its area.
3. No resources will be shared between homesteads.

The SMEs' assumed that each homestead will have a single water well drilled into the deep aquifers of the NTS region. The drilling technology is consistent with that used at settlements in alluvial valleys of the southern Great Basin. The total number of wells drilled during the evaluation period for this scenario is influenced primarily by the potential for homesteading in these areas and the expected lifetime of a homestead.

The SME input indicated that independent homesteading is extremely unlikely to occur in Frenchman or Yucca Flats. The total number of wells anticipated over the course of the 10,000-year evaluation period is very small for this scenario (approximately 20), leading to a probability of IHI of around 0.03%. This probability estimate is founded on the assumption that management controls are ineffective, and the waste footprint size is two acres.

Base Community Scenario: The Base Community Scenario consists of locating a community within Frenchman or Yucca Flats (Figure 1). Each alluvial basin area was evaluated separately for the community scenarios. Assumptions for this scenario include:

1) Only one community may exist in Frenchman or Yucca Flats at a given time.
2) Each community starts with four production wells.
3) Resources are shared within the community.

The types of future communities envisioned by the SMEs include a research park, prison facility, military base, religious group, or a casino. The probability of a community being located in Frenchman or Yucca Flats was considered by the SMEs to be very small because of the hostility of the environment, as well as the distance from a population center for infrastructure support services. The total number of wells drilled during the evaluation period was influenced by the potential for a community to settle in these areas, the expected lifetime of a community, and the expected lifetime of a production well. If one of the four production wells ceases to function, then a replacement well was assumed to maintain the community water supply. There may be several replacement wells drilled during the community lifetime that would be located within the boundaries of the community well field.

For all the community scenarios, the SMEs considered settlement in Frenchman Flat to be more likely than in Yucca Flat. They considered the heavily-cratered areas of Yucca Flat, where the Area 3 RWMS is located (Figure 2), much less likely to be settled than elsewhere in the basin. The SMEs indicated that the planned community considered for this scenario was extremely unlikely to occur. Given the expected lifetime of each community that may exist in these areas, and the expected lifetime of a production well, within the next 10,000 years the number of wells drilled in Frenchman Flat is less than 20. This small number of wells yielded a probability of IHI of approximately 0.03%. The number of drilled wells in the heavily-cratered area of Yucca Flat under this scenario was expected to be considerably less, resulting in an estimated probability of 0.003%.

Las Vegas Expansion Scenario: Given current population trends, the SMEs considered it reasonably likely that expansion of Las Vegas would exert population pressures on Frenchman and Yucca Flats. This scenario, and the Jackass Flats Scenario, represent hybrids between the Homestead and Base Community Scenarios because they assume that the spillover population operates as "commuting-homesteaders," who rely on the central community for a variety of resources. However, each of these commuting-homesteaders drill their own water well. The total number of wells drilled was influenced by the potential for Las Vegas to expand sufficiently that it places population pressures on Frenchman or Yucca Flats, the expected lifetime of Las Vegas, the expected number of homesteads that are settled in Frenchman and Yucca Flats, and the expected lifetime of a private well. If a private well ceases to function, then a replacement well is installed as before.

This type of scenario was more likely to occur than the Base Community Scenario. The number of wells drilled in Frenchman Flat in 10,000 years is approximately 300, including replacement wells. The resultant scenario probability of IHI is approximately 0.2%. The number of wells drilled in the heavily-cratered area of Yucca Flat was considerably less, resulting in a probability of 0.01%.

Jackass Flats Scenario: This scenario consists of locating a community in an area near Frenchman and Yucca Flats. Jackass Flats is centrally located in the vicinity of the Flats of interest (Figure 1). The assumption is that there are many areas around NTS that would be more desirable than Frenchman or Yucca Flats for community settlement, but that such communities would place population pressure on these two areas. For example, a community that develops in Jackass Flats, or around the current infrastructure of Mercury (Figure 1), is considered large enough to spill population over into neighboring valleys.

The opinion of the SMEs was that this type of scenario is likely to occur, and that communities of this type can be expected to be present intermittently for approximately 5,000 years out of the evaluation period. The number of wells drilled in Frenchman Flat was thought to be approximately 5,000. The resultant scenario probability of IHI is approximately 10%. The number of wells drilled in the heavily-cratered area of Yucca Flat under this scenario was considerably less, resulting in an estimated probability of approximately 1%.

The Jackass Flats Scenario clearly dominates the total assessment of the probability of IHI. Therefore, the probabilities derived for this scenario represent the total probabilities of IHI for Frenchman and Yucca Flats. The likelihood of IHI occurring is small, even if management control factors are completely ineffective. The effectiveness of management controls modify this probability to reduce the occurrence of IHI.

Management Controls

The probability assessments for each scenario are derived separately from the management controls. If management controls are found to be effective, then the scenario probabilities are modified accordingly. Five management controls are considered to be pertinent (Figure 5): institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers. The underlying assumption is that if management controls are functional, IHI is *not possible.*

The first factor included in Figure 5, institutional control, includes options ranging from current security-controlled access of the NTS, zoning restrictions, Federal or State ownership of designated lands, to periodic patrols of sensitive areas. Institutional controls are maintained to ensure that certain activities will not jeopardize the integrity of the waste disposal site. If institutional control of the NTS or the RWMSs is not maintained for the full evaluation period, then the other nodes of the management, homestead, and community modules become important.

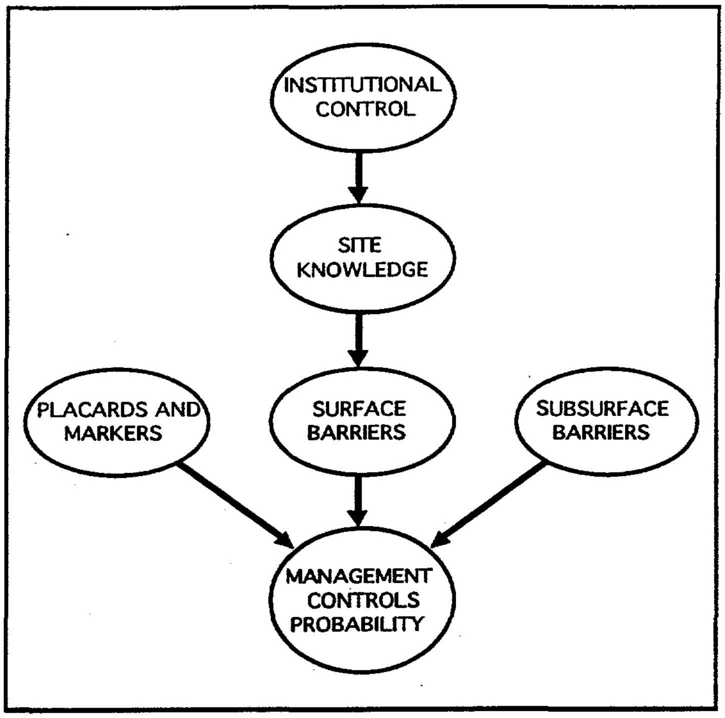

Figure 5: Influence diagram of factors in the management controls model.

The second factor of the management controls module concerns site knowledge of the waste sites (Figure 5). The SMEs' definition of site knowledge refers to written or oral communication, or societal memory, of the existence of the waste sites. This factor presumes that, if site knowledge is retained, IHI *will not* occur. The SMEs noted that persons settling in Frenchman or Yucca Flats will either have, or not have, knowledge of the past use of portions of the NTS as waste disposal areas. Consequently, there is the possibility that some individuals may be attracted to, or knowingly intrude into waste disposal areas (Black et al., 1996). However, by definition, these individuals cannot be considered *inadvertent* human intruders, and therefore are not included in the probabilistic assessment.

The SMEs decided that the potential for institutional control or site knowledge to last for 10,000 years was highly unlikely. Their opinion concurred with those of the workshop participants. Elicited input for the institutional control and site knowledge factors indicate less than 500 years of combined effectiveness. It was considered more likely that control would be lost gradually, rather than by catastrophe. The SMEs considered several mechanisms for gradual erosion of institutional control and loss of site knowledge: political change, economic constraints, or less concern by society for the importance of waste management issues.

The three remaining management controls (Figure 5) consist of physical deterrents:

1. Placards and markers are informational signs or symbols placed near, or above, the waste site that are designed to warn against intrusion into the underlying waste.
2. Surface barriers are engineered structures placed over the waste or closure cap that may prevent siting of the drill rig, or the drilling operation.

3. Subsurface barriers are engineered structures below the ground surface, but above the waste, that are constructed intentionally to deter intrusion. Barrier materials included concrete, rock, metal, rubber, and so on for SME evaluation.

The SMEs evaluated the potential effectiveness of these physical deterrents. They argued that placards and markers designed to current societal interpretations are unlikely to maintain their intended meaning in the future, unless their design is relatively simple. A simple warning sign was designed by the SMEs that depicts the waste buried at depth with upright and prone bodies symbolizing the concepts of life and death.

The panel concluded that a surface barrier can be designed and constructed that would effectively deter drilling. Effectiveness of the surface barrier was defined by the inability of the driller to locate and set-up a rig atop the waste site. They reviewed current designs and structures and judged them to be ineffective, so they developed their own barrier designs. The central design theme was a high (about 3 meters), steep-sided mound (or closure cap), armored or surrounded with large boulders that would make drill-rig siting difficult to impossible.

It was concluded that cost-effective subsurface barriers cannot be designed or constructed, because human curiosity or technology would eventually penetrate all barriers. However, the SMEs indicated that the subsurface barrier most likely to interfere or prevent drilling would consist of at least 1.5-meter-thick concrete with 2.54-centimeters-thick rebar reinforcement, spaced to no-greater-than 18-centimeters apart.

Assuming that the most favorable surface barrier described is effective at a probability of 95%, as suggested by the SMEs, this management control modifier can be applied to the scenario probabilities. If it is applied to the worst case Jackass Flats scenario, then based on the SME input, the overall probability of IHI at Frenchman Flat is less than 1%; for Yucca Flat, it is less than 0.1%. If this management control, or another equally effective management control were implemented, then these probabilities reasonably reflect the overall probability of IHI for a footprint of two acres corresponding to waste buried in the Area 3 and 5 RWMSs at the NTS.

CONCLUSIONS

- Site-specific and credible scenarios for the intruder-driller were developed through workshop discussions involving stakeholders, scientists, and the public, as well as by the SME panel. Four intruder-drilling scenarios were derived: the standard Homestead Scenario, the Base Community Scenario, the Las Vegas Expansion Scenario, and the Jackass Flats Scenario. Of these four, the SMEs determined that the Jackass Flats Scenario is most likely, occurring for around 5,000 years of the 10,000-year evaluation period in either Frenchman or Yucca Flats. A community in Jackass Flats was considered large enough to spill population over into adjacent valleys, creating "commuting homesteaders." The probability of IHI for the Jackass Flats Scenario is about 10% for Frenchman Flat (the Area 5 RWMS location), and about 1% for Yucca Flat (the Area 3 RWMS location). The lower probability of IHI in Yucca Flat is attributed to the presence of surface-subsidence craters, created by underground testing, that effect the expected number of drilled wells.

- Of the five management control factors (institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers) assessed in the elicitation, surface barriers were found to be potentially the most effective in reducing the probability of IHI. The SMEs determined that a surface barrier designed to prevent the driller from setting up a drill rig atop the waste site would be 95% effective. The subsurface barriers and placards and markers were considered less likely to deter intrusion than a well-designed surface barrier. A simple warning sign, which the SMEs illustrated, may reasonably provide a 50% probability of effectiveness. Elicited input for the institutional control and site knowledge factors indicate less than 500 years of combined effectiveness over the 10,000-year evaluation period. It was considered more likely that control would be lost gradually, rather than by catastrophe. The SMEs considered several mechanisms for gradual erosion of institutional control and loss of site knowledge: political change, economic constraints, or less concern by society for the importance of waste management issues.

- Assuming that the surface barrier described by the SMEs is effective at a probability of 95%, the resultant Jackass Flats Scenario probabilities for Frenchman and Yucca Flats can be further modified by the effectiveness of the surface barrier to deter IHI. Applying the surface barrier effectiveness to the worst-case Jackass Flats Scenario, the overall probability of IHI in Frenchman Flat is less than 1%, and less than 0.1% in Yucca Flat. Yucca Flat is a better choice for waste-site location to reduce the probability of IHI, given the intruder-drilling mechanism.

- The probabilistic approach to assessing the intruder-driller for NTS PAs resulted in more site-specific, credible scenarios; yields significantly lower probabilities of 10%, or less, for Frenchman and Yucca Flats; and provides a means of describing and quantifying management control options now, and into the future. On the other hand, the deterministic approach to PA assumes that IHI by drilling *will* occur at a probability of 100%. As demonstrated in this study, probabilistic PA results for the NTS are more realistic, and have proven successful in evaluating problematic waste streams (Brown et al., 1996) that require a more thorough and rigorous method of analysis.

- Periodic review of intrusion is proposed by the SMEs, at an interval of 25 years, to reassess probabilistic estimates given that changes in society (political, economic, cultural, etc.) or technology will affect the results of the evaluation. Sufficient funds should be allocated now to ensure that periodic review of intrusion will occur.

- A major conclusion and recommendation of this study is the need for further work regarding alternative options for implementation of management controls. The effectiveness of management controls are dependent on DOE policy decisions. The SMEs concluded in the elicitation that the absence of clear DOE policy regarding management controls increased the uncertainty of their estimates. Further work in this area can be conducted through decision analysis that incorporates factors such as cost, construction, and schedule to identify the most appropriate decision action to deter drilling associated with IHI.

REFERENCES

BLACK, P.K., L.P. MATHAI, M.M. HOOTEN, K.J., BLACK, and M.D. NEPTUNE, "Assessing the Probability of Inadvertent Human Intrusion at Nevada Test Site Radioactive Waste Management Sites," U.S. Department of Energy, Nevada Operations Office, Draft Report (Unpublished) (1996).

BLACK, P.K., M.D. NEPTUNE, R.T. RYTI, and D.D. HICKMOTT, "Professional Judgment in the Data Quality Objectives Process: A Bayesian Approach to Screening Assessment," in Proceedings of the Federal Environmental Restoration III and Waste Minimization II Conference, Hazardous Materials Control Resources Institute (1994).

BROWN, T.J., W. BEYELER, J. COCHRAN, H. STOCKMAN, P. BLACK, L. PRICE, S. WIRTH, and L. BARKER, "Performance Assessment for the Disposal of Fernald 11e(2) Byproduct Material in Deep Trenches at the Area 5 RWMS on the Nevada Test Site," U.S. Department of Energy, Nevada Operations Office, Draft Report (Unpublished) (1996).

CASE, M.J., and M.D. OTIS, "Guidelines for Radiological Performance Assessment of DOE Low-level Radioactive Waste Disposal Sites," U.S. Department of Energy, Idaho Operations Office, DOE/LLW-62T (1988).

CASTI, J.L., "Searching for Certainty: What Scientists Can Know About the Future," William Morrow and Company, Inc. (1990).

KEENEY, R.L., and H. RAIFFA, "Decisions with Multiple Objectives," Cambridge University Press (1993).

KOTRA, J.P., M.P. LEE, N.A. EISENBERG, and A.R. DeWISPELARE, "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program," U.S. Nuclear Regulatory Commission, Public Comment Draft from Internet (1996).

MEYER, M. and J. BOOKER, "Eliciting and Analyzing Expert Judgment: A Practical Guide," Academic Press (1991).

MORGAN, M.G. and M. HENRION, "Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis," Cambridge University Press (1995).

RAIFFA, H., "Decision Analysis: Introductory Lectures on Choices Under Uncertainty," Addison-Wesley (1968).

SHOTT, G.J., C.J. MULLER, L.E. BARKER, D.E. CAWLFIELD, F.T. LINDSTROM, D.G. LINKENHEIL, M.J. SULLY, L. McDOWELL-BOYER, and D.J. THORNE, "Performance Assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County, Nevada," Bechtel Nevada Draft Report, DOE/NV11432-196 (1996).

WINOGRAD, I.J., "Radioactive Waste Disposal in Thick Unsaturated Zones," Science 212(4502): 1457-1464 (1981).

WOOD, D.E., R.U. CURL, D.R. ARMSTRONG, J.R. COOK, M.R. DOLENC, D.C. KOCHER, K.W. OWENS, E.P. REGNIER, G.W. ROLES, R.R. SEITZ, and M.I. WOOD, "Performance Assessment Task Team Progress Report," Idaho National Engineering Laboratory Report, DOE/LLW-157, Rev. 1 (1994).